Visiting Exoplanet Host Stars Using the CHARA Array

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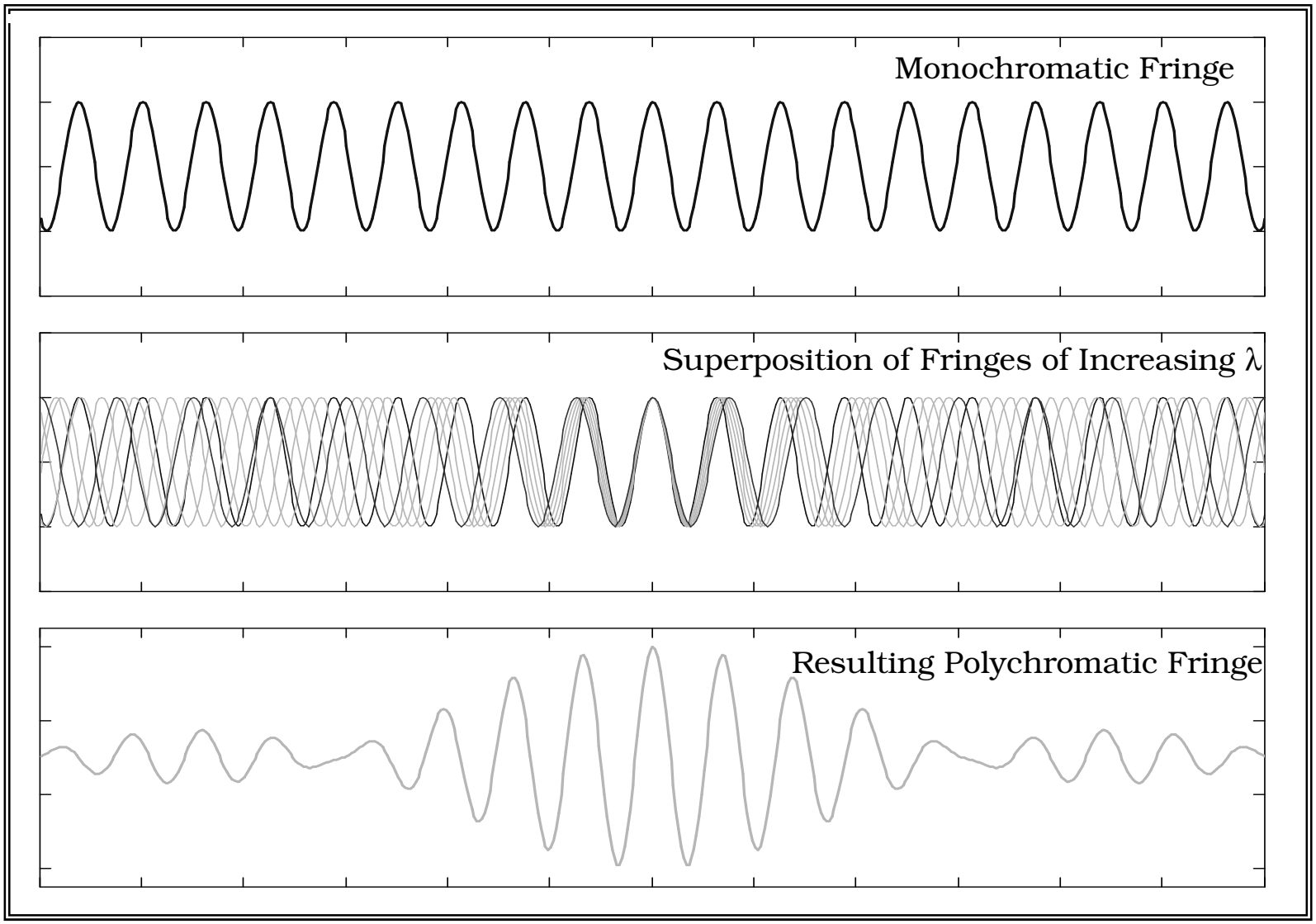
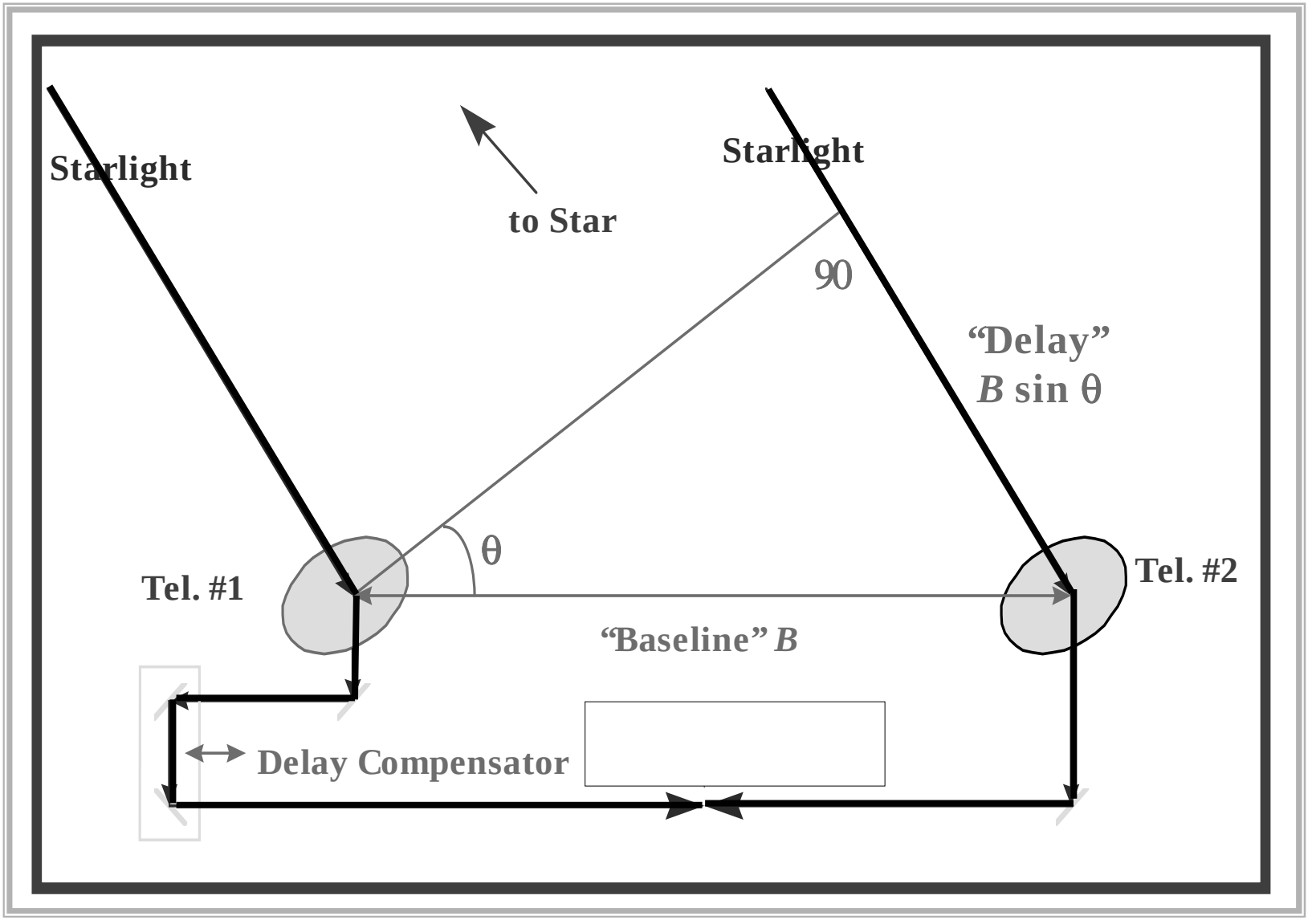
Talk Outline

- Interferometry
- CHARA facilities
- Characterizing exoplanet systems
  - Measure angular diameters
  - Check for stellar companions

Effect of $\Delta\lambda$ on Fringes

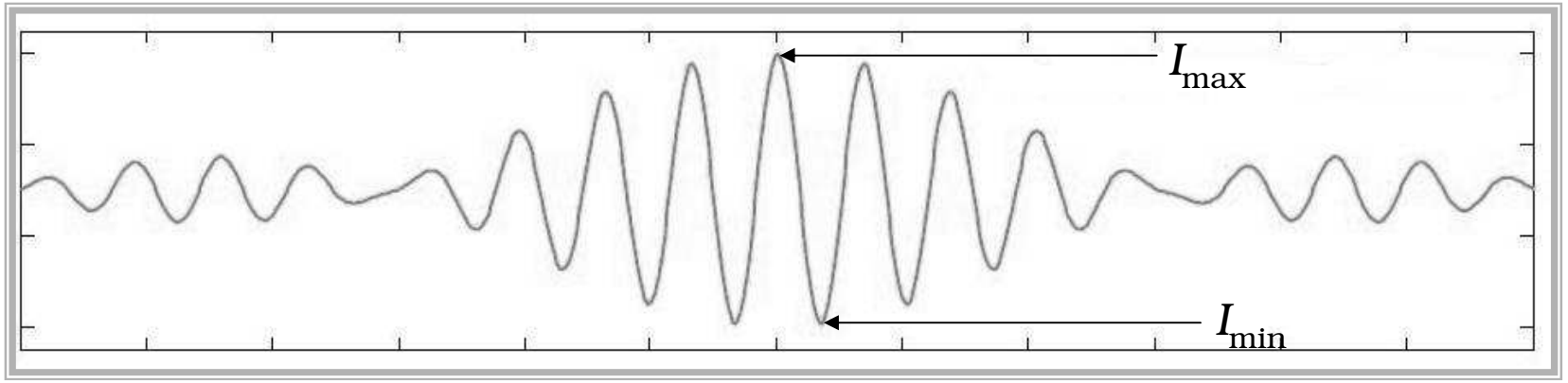


Basic Interferometer



Visibility - Easy

$$V = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$$



- V=0 → fully resolved
- V=1 → completely unresolved

Visibility – Less Easy

$$V^2(b,\Theta,\lambda)=(1-\beta)^{-2}\{\beta^2V_1^2+V_2^2+2\beta V_1V_2\cos[2\pi b\lambda^{-1}\rho\cos\psi]\}$$

$$V_{1,2}(b,\Theta,\lambda)=2[J_1(\pi\Theta_{1,2}b/\lambda)]/(\pi\Theta_{1,2}b/\lambda)$$

b=baseline

β=brightness ratio

ρ=angular separation

J_1=Bessel function

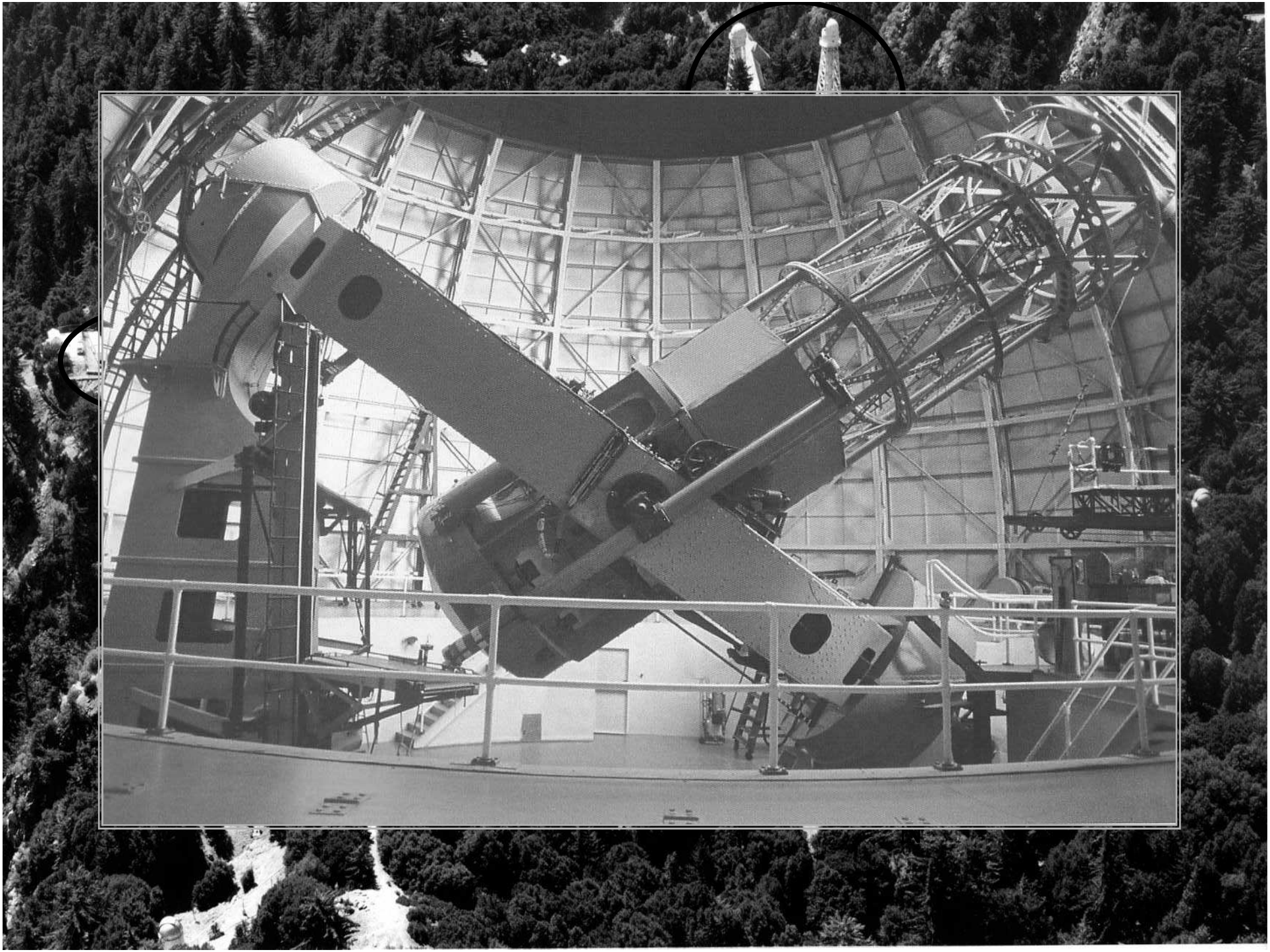
λ=wavelength

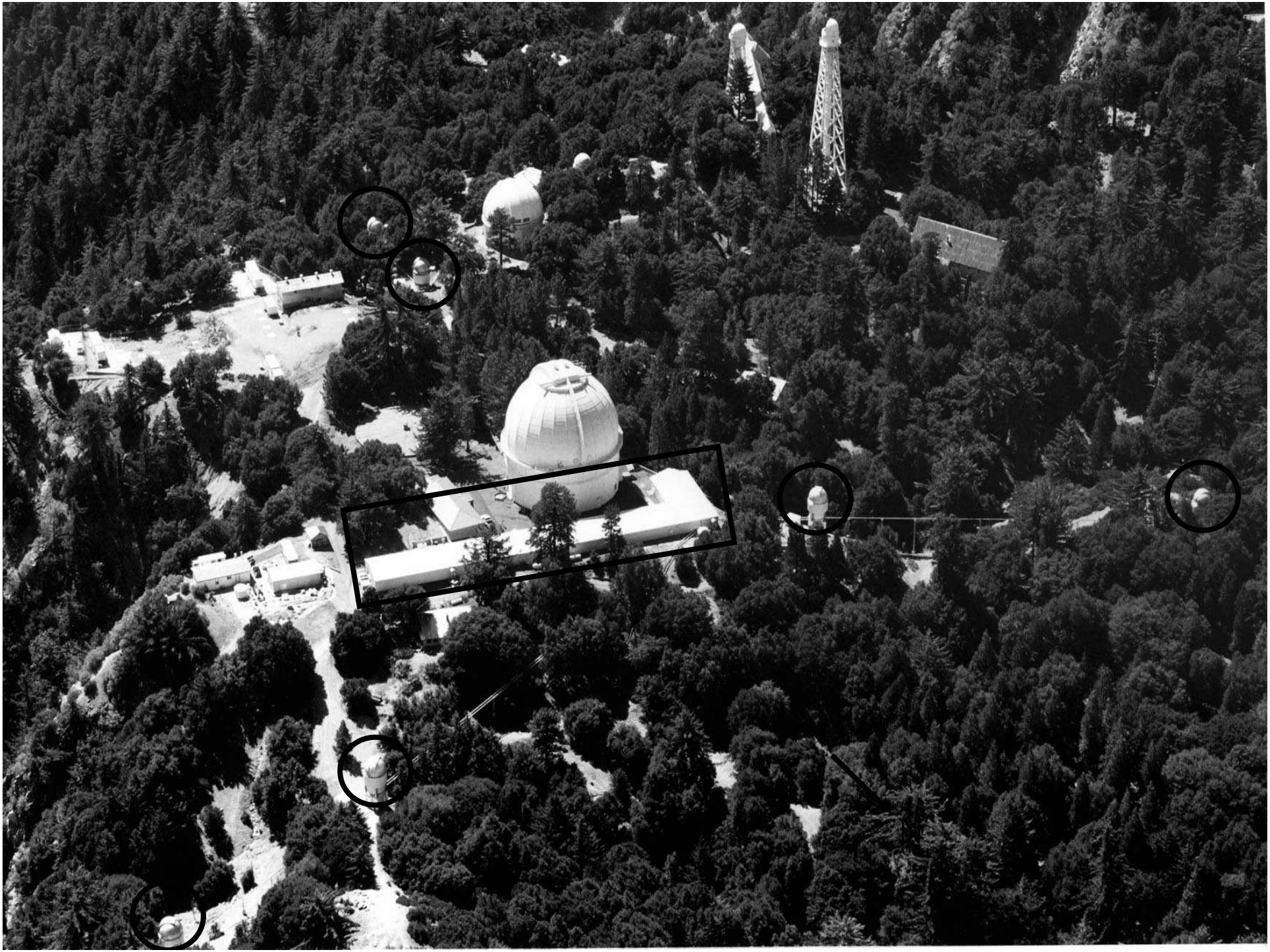
Θ=angular diameter

ψ=difference in position angle of binary and b

CHARA Array

- Y-shaped configuration of six 1-m scopes
  - 15 baselines from 34 – 331 meters
- Three operating regimes:
  - 470 - 800 nm
  - 2.15 μm
  - 1.65 μm
- Limiting magnitudes:
  - *V*-band = 9.0
  - *K*-, *H*-band = 6.5





Telescope Enclosures

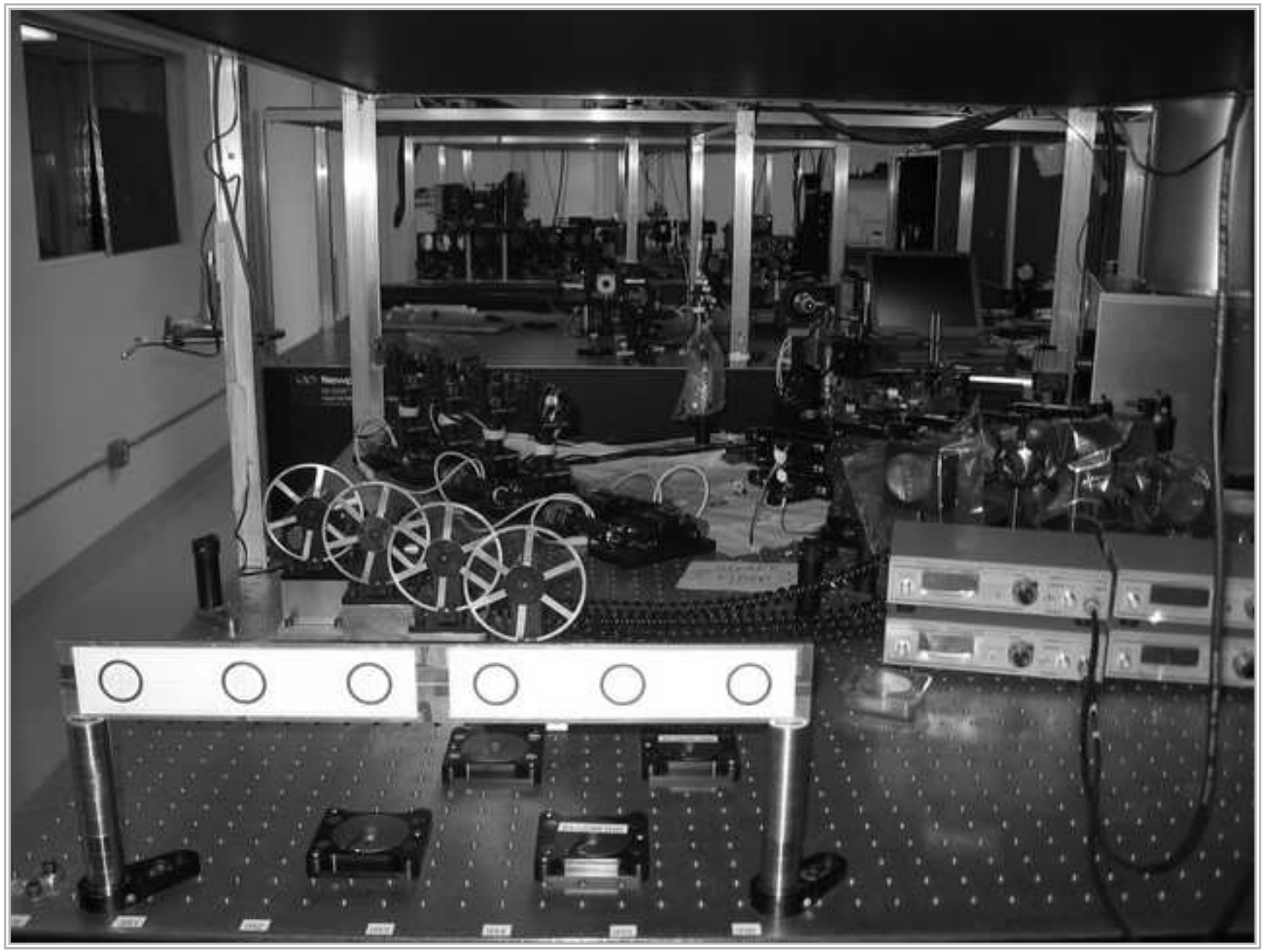
Telescopes

Vacuum Light Pipes

Pipes of Pan

OPLE Carts

Beam Combiner Lab



Remote Operations

CHARA Collaborators

- **CHARA/GSU**
  - Provides faculty, staff & graduate students
  - Directs operations & provides operating budget
- **National Optical Astronomy Observatory** (S. Ridgway)
  - Member of original core design team
- **University of Paris, Meudon** (V. du Foresto)
  - Provides the FLUOR 2-way beam combiner for high precision *V*
- **University of Sydney** (P. Tuthill)
  - Provides southern hemisphere access at SUSI
- **University of Michigan** (J. Monnier)
  - Developing IR fringe tracking and the MIRC 4-way beam combiner for closure phase measurements
- **Michelson Science Center, JPL/Caltech**
  - Provides funding for access to observing
- **Observatoire de la Côte d'Azur** (D. Mourard)
  - Visible spectrograph and polarimeter, VEGA

Exoplanets

Exoplanets + CHARA

- Characterize host stars
- Measure angular diameters
  - Leads to R_{linear}, M, age
- Check for stellar companions

Previous Estimates

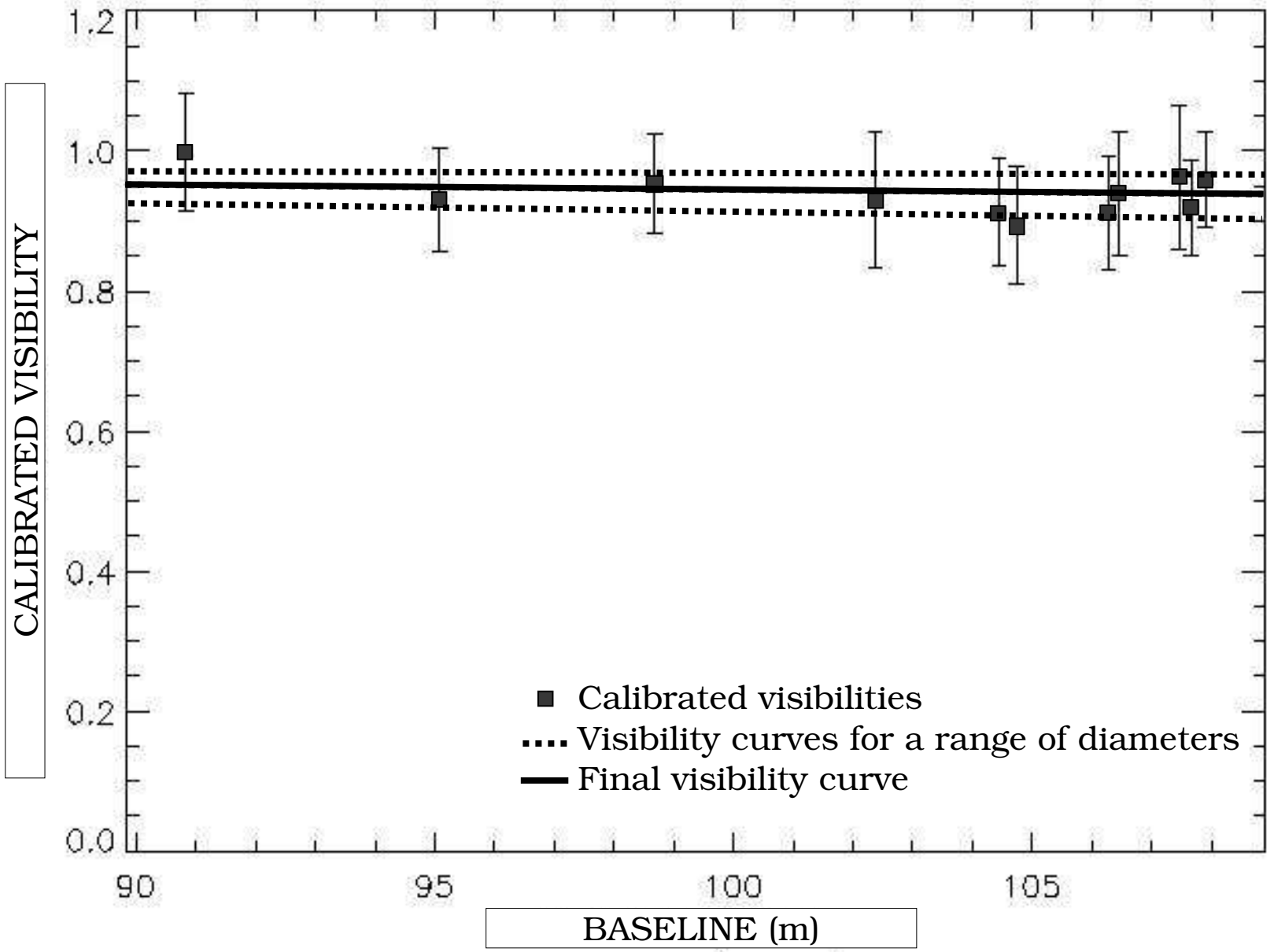
- Ribas et al. (2003):
  - Match 2MASS photometry to synthetic photometry to estimate $T_{\rm eff}$
  - Use $T_{\rm eff}$ to estimate diameters
- Fischer & Valenti (2005):
  - Estimated radii using luminosities derived from $T_{\rm eff}$, parallax, and a bolometric correction

Select Calibrators

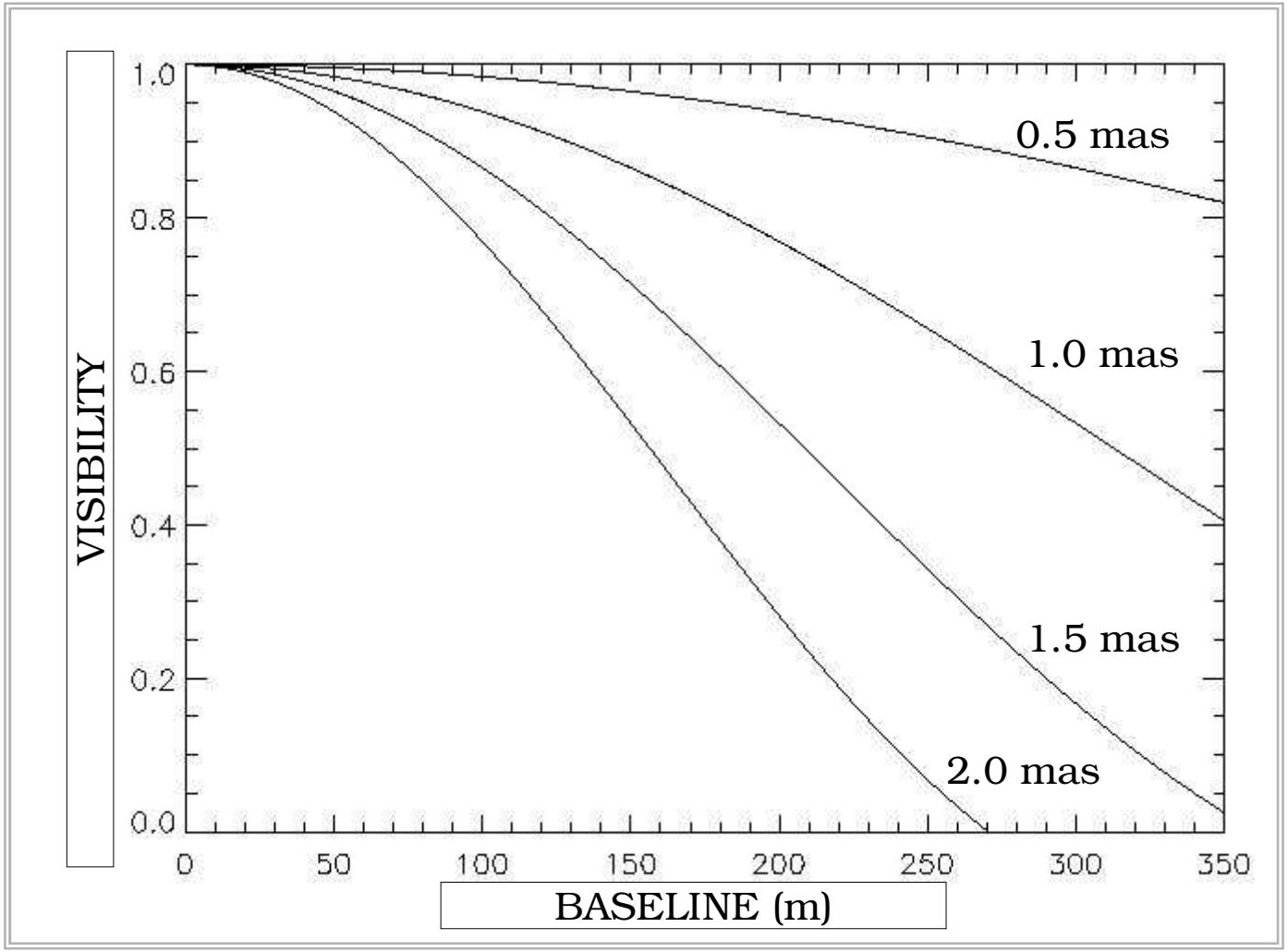
- Single, slowly rotating, boring stars
- Act as the standard to which you measure your target star
- Observe cal – target – cal – target – cal, etc.
- Removes instrumental and seeing effects

Method

- Calibrate target's visibility points
- Fit visibility curves for a range of stellar diameters
- Best fit curve → the corresponding diameter is the answer


CALIBRATED VISIBILITY
1.2
1.0
0.8
0.6
0.4
0.2
0.0
90
95
100
105
BASELINE (m)
Calibrated visibilities
Visibility curves for a range of diameters
Final visibility curve

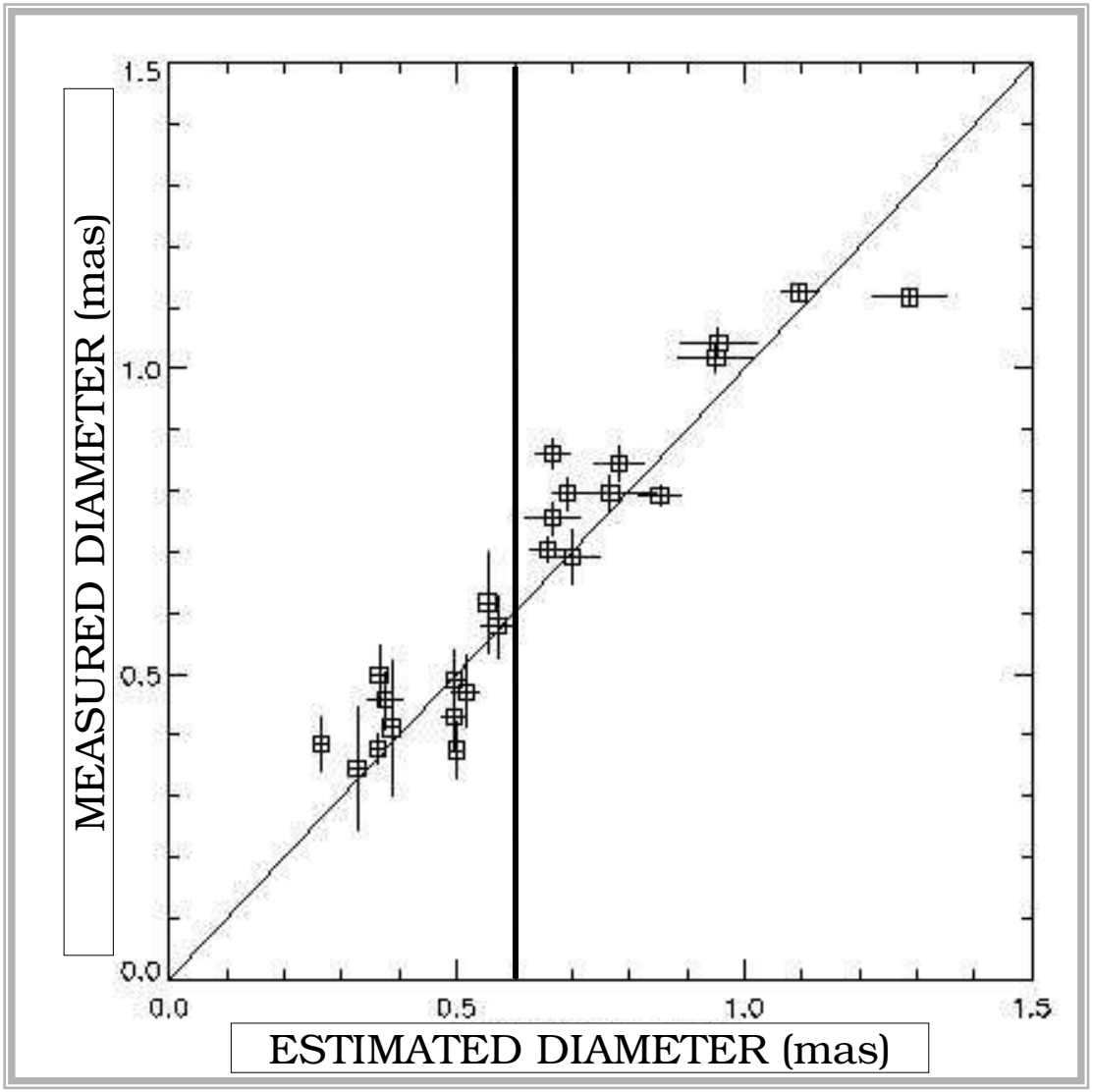
Diameter Effects



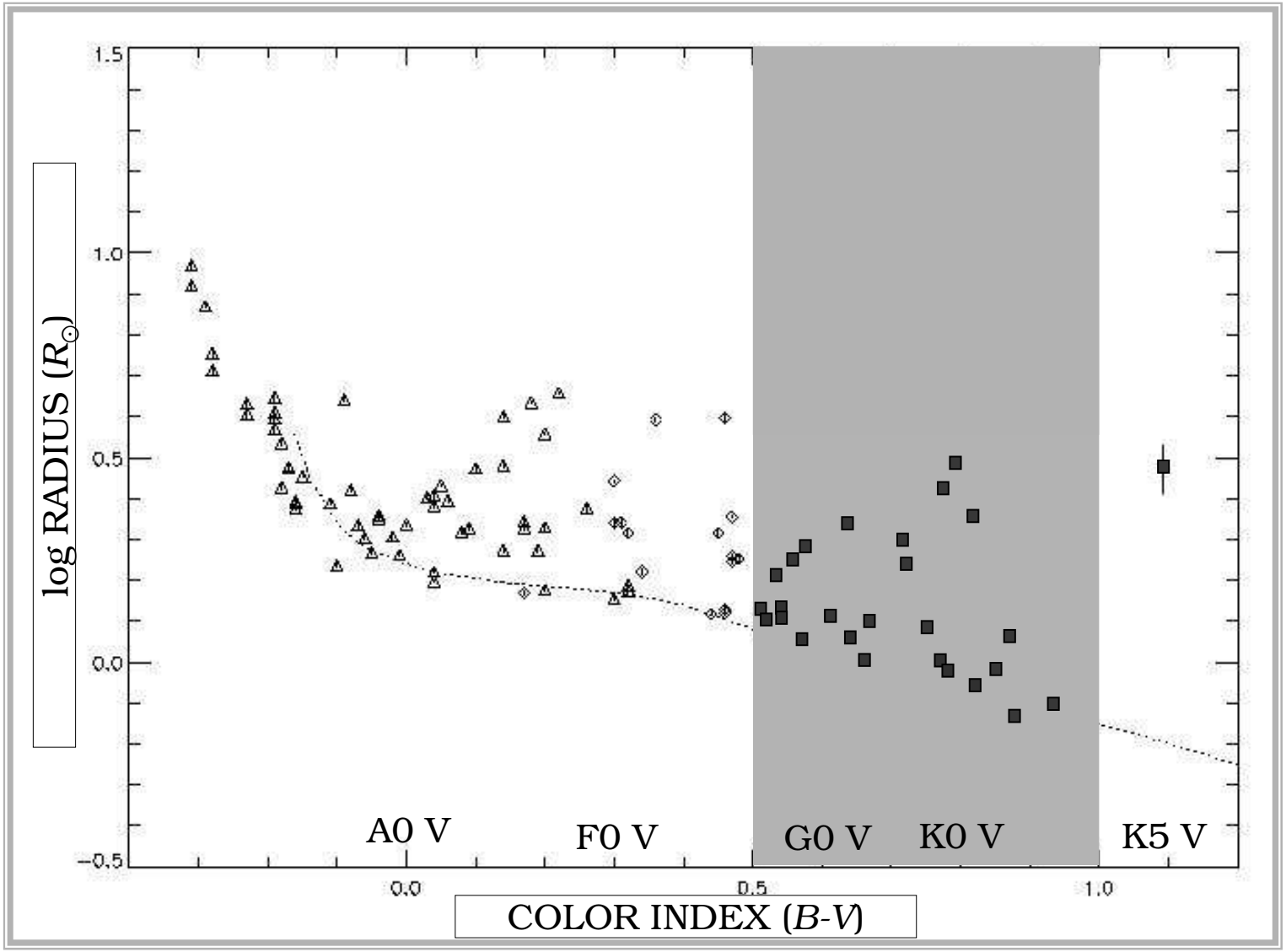
Observations

- Measured 24 host stars
- January 2004 - September 2007
- Stars were chosen by *K* magnitude and declination
- Used *K*-band for all but HD 189733

Measured vs. Estimated Diameters



CHARA + Andersen 1991



Baines et al. 2008, ApJ, June 20

Results

- Of the 24 host stars:
  - 3 giants
  - 5 subgiants
  - 11 dwarfs
  - 5 moderately evolved stars

- Many planets orbit *evolving* stars

What do diameters tell us?

- Angular diameter, parallax → R_{linear}
- R_{linear}, M, metallicity → age

BUT

- Age highly dependent on stellar mass
- Mass not well known

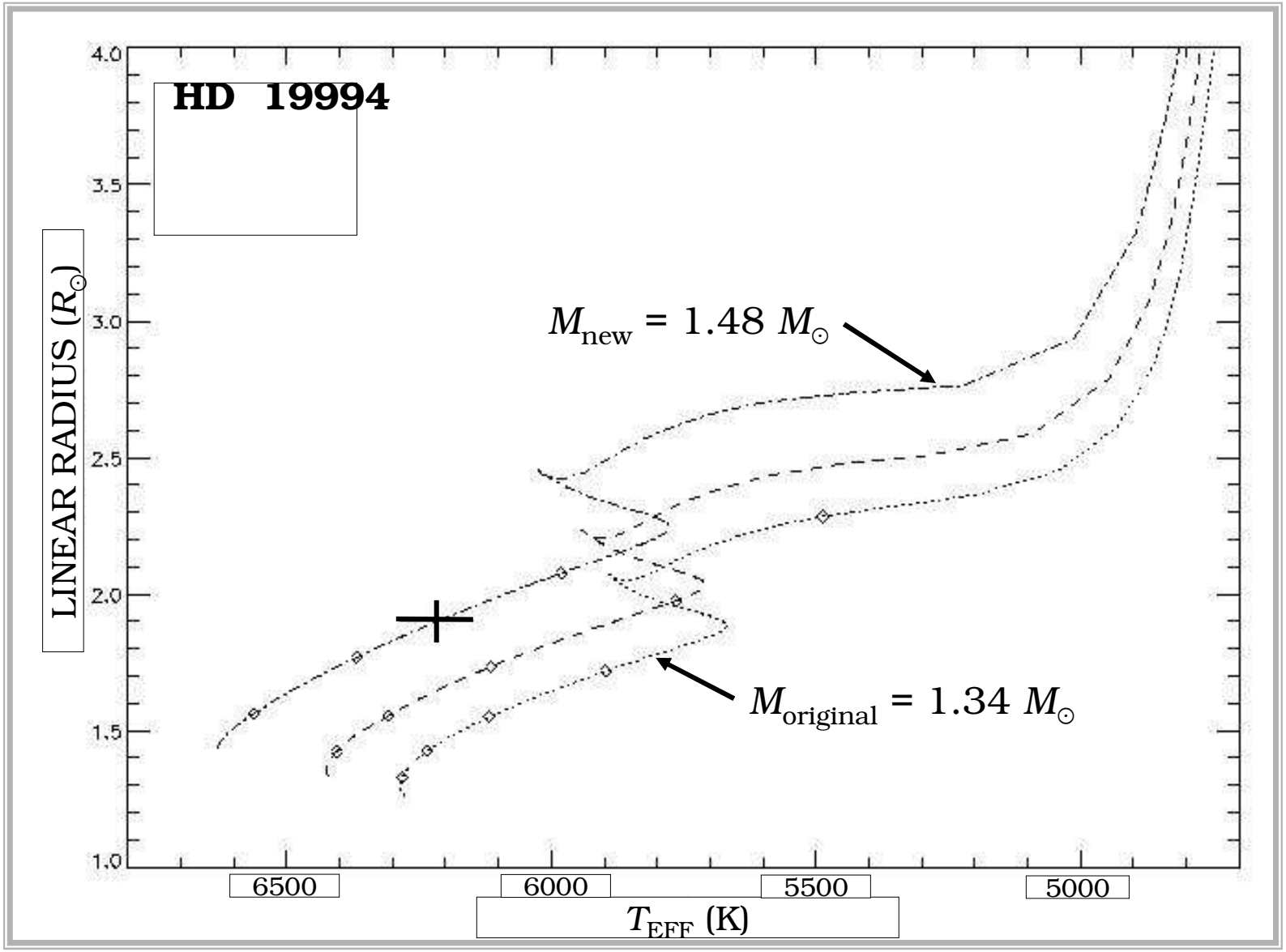
Solution?

Create range of evolutionary tracks using a stellar model

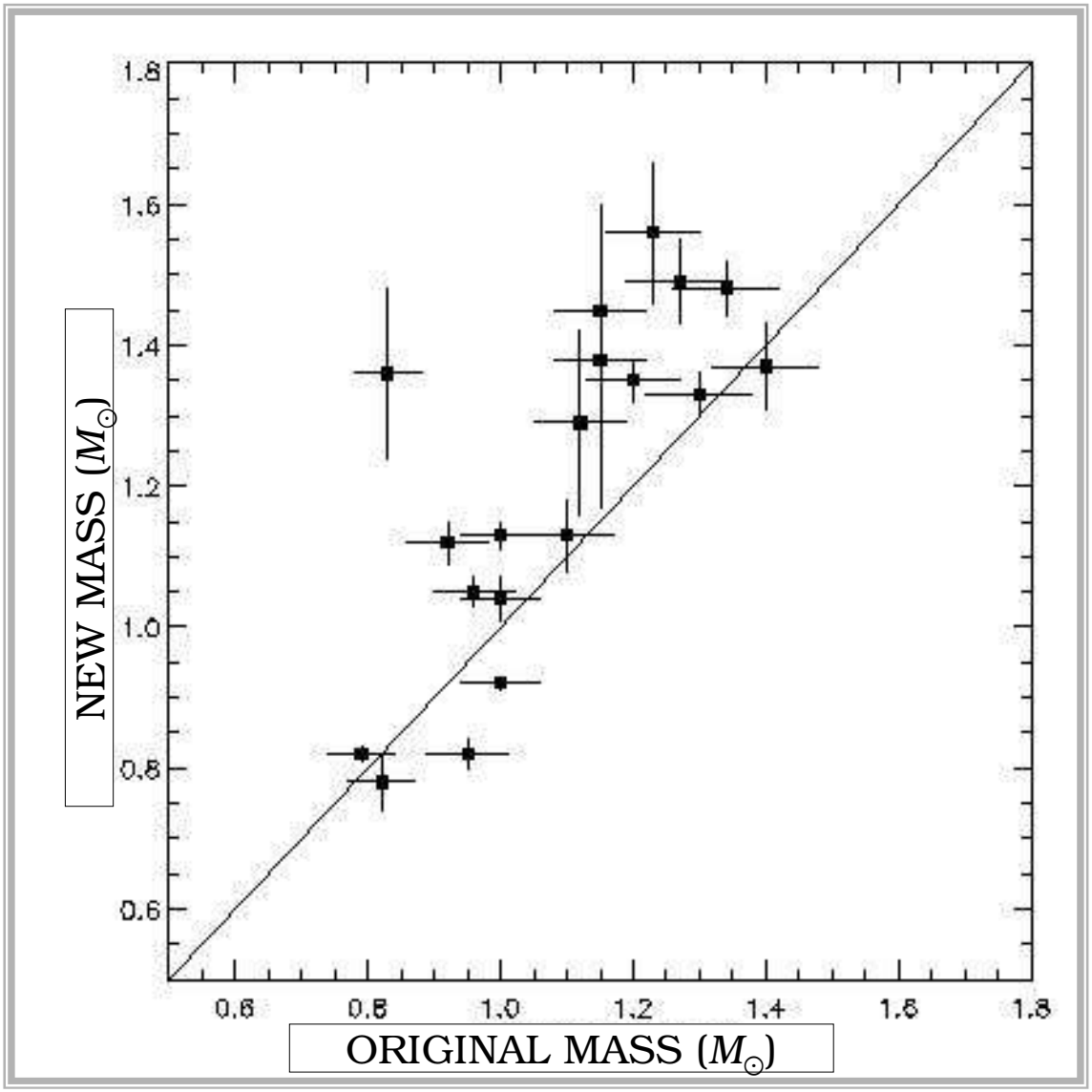
- *Dartmouth Stellar Evolution Simulator* (http://stellar.dartmouth.edu/~evolve)

Match to:

- R_{linear} from interferometry
- T_{eff} from spectroscopy (Santos et al. 2004)

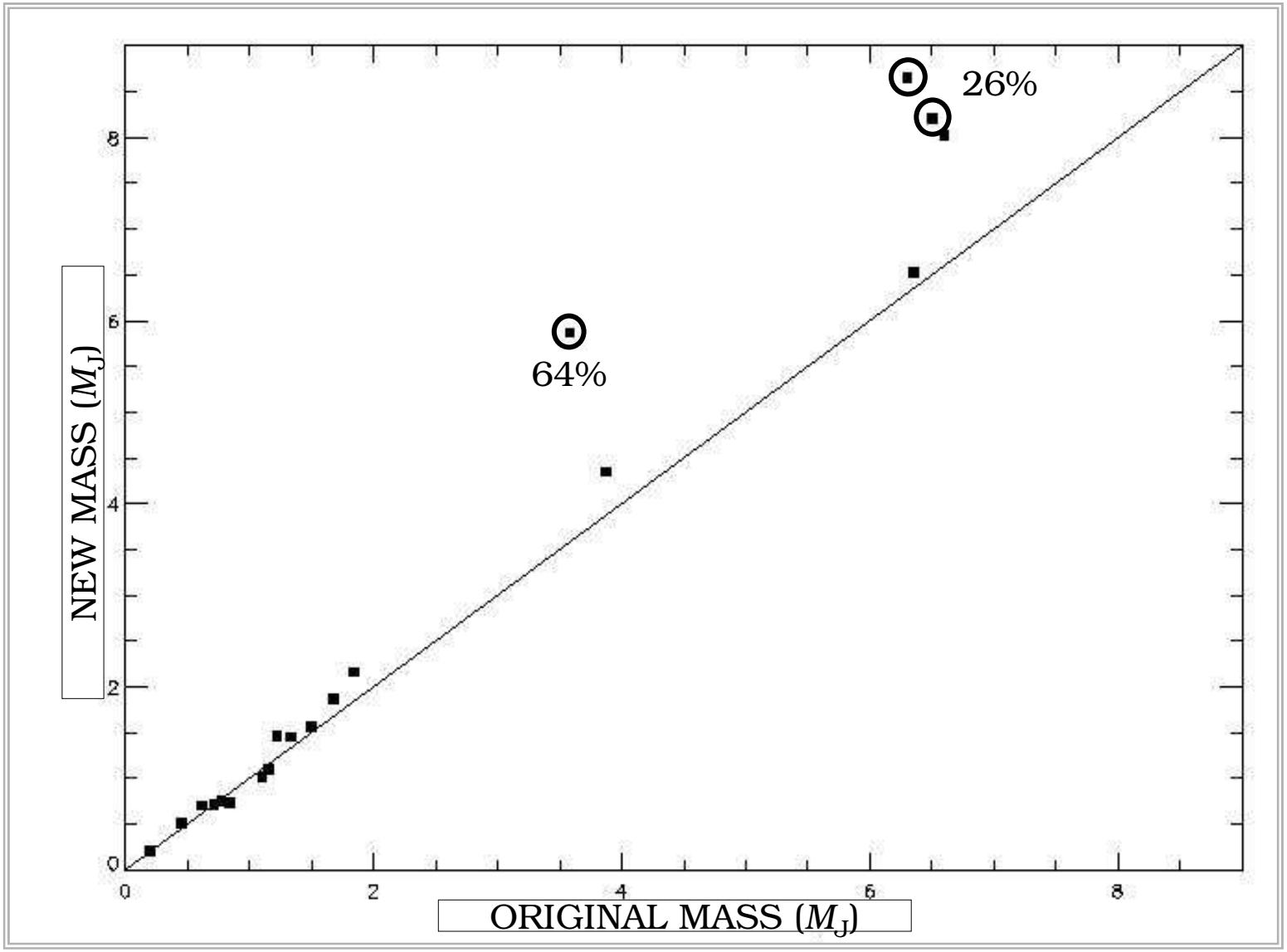

HD 19994
LINEAR RADIUS ($R_\odot$)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
M_{new} = 1.48 $M_\odot$
$M_{original}$ = 1.34 $M_\odot$
6500
6000
5500
5000
T_{EFF} (K)

Stars: New vs. Old Mass



- Ave diff = 14%
- New masses changes ages drastically

Planets: New vs. Old Mass



Transiting Planet Diameter

HD 189733

- Discovered by Bouchy et al. (2005):
  - $R_\star = 0.76 \pm 0.01\ R_\odot$
  - Planet-to-star-radii ratio: 0.172 ± 0.003

$$R_{\rm planet} = 1.26 \pm 0.03\ R_{\rm Jup}$$

- Bakos et al. (2006) refined planetary parameters:

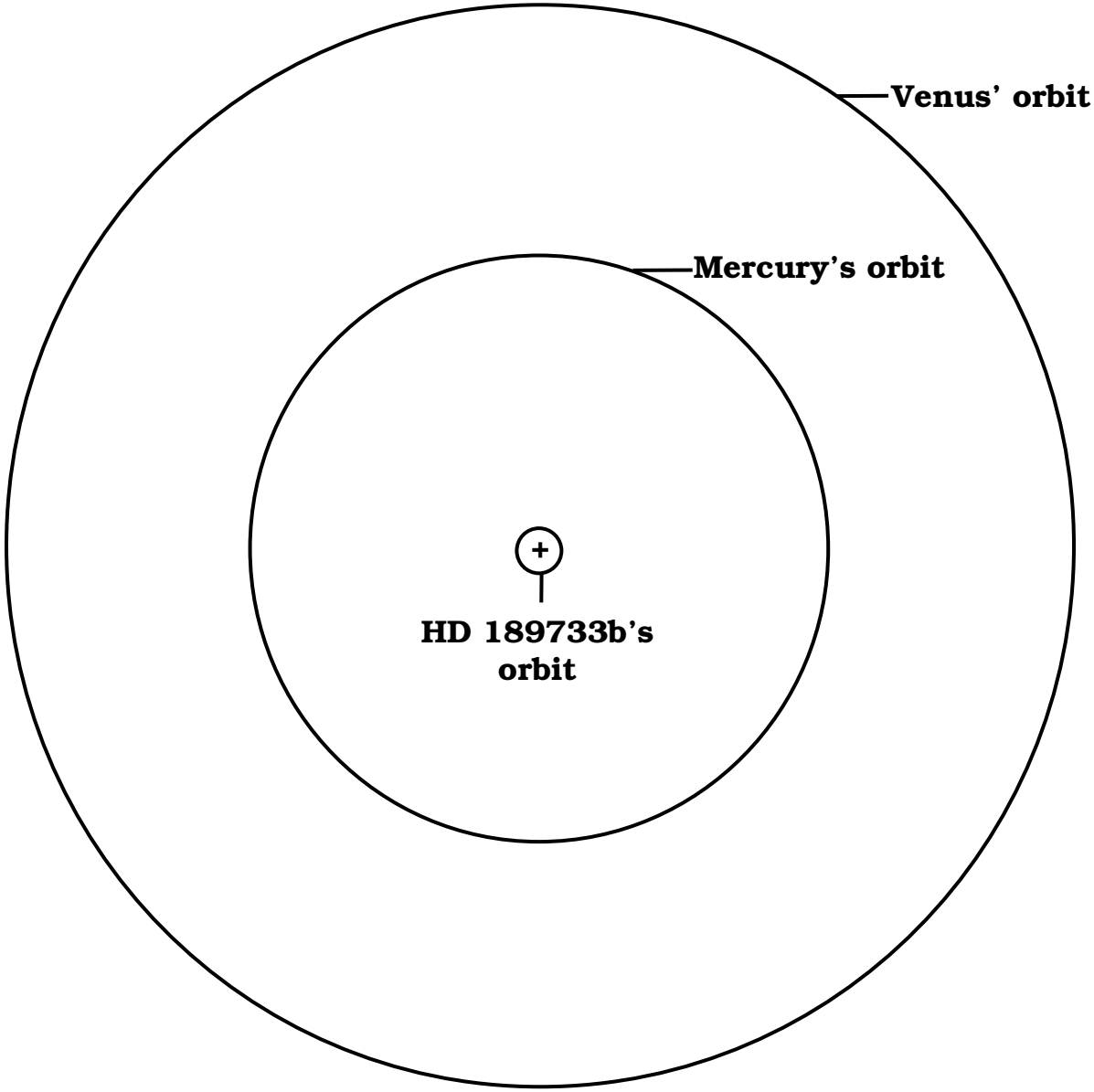
$$R_{\rm planet} = 1.154 \pm 0.032\ R_{\rm Jup}$$

Baines et al. 2007, ApJ, 661, L195

CHARA Results

- $\Theta_{LD} = 0.376 \pm 0.031$ mas
- $\pi = 51.9 \pm 0.9$ mas
- $R_\star = 0.779 \pm 0.066\ R_\odot$

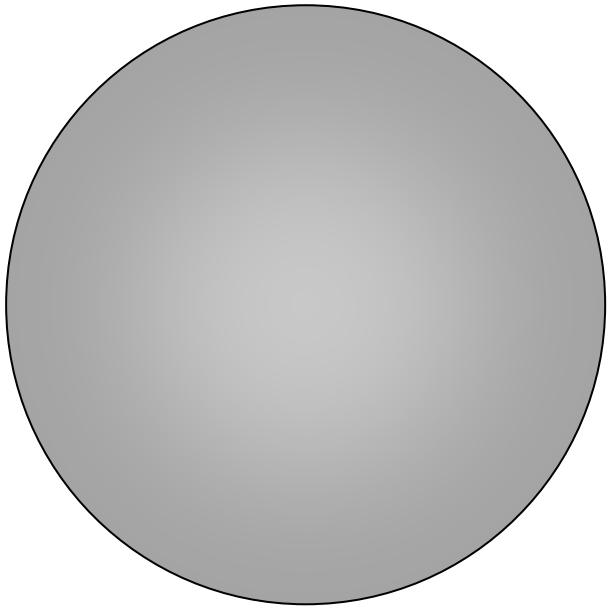
$$R_{planet} = 1.19 \pm 0.10\ R_{Jupiter}$$
$$\rho = 0.91 \pm 0.23\ g\ cm^{-3}$$


Venus' orbit
Mercury's orbit
HD 189733b's orbit

Sun

Jupiter

HD 189733



HD 189733b

The Search for Stellar Companions

Baines et al. 2008, ApJ, July 20

Basic Premise

In radial velocity observations:

Face-on binary

=

Higher-inclination planet

Interferometry doesn't care about *i*

Stars vs. Planets

- Orbital element distributions for exoplanets and SBs are statistically identical (Stepinski & Black 2001)

- Models of 8 exoplanets as binary systems match observations (Imbert & Prévot 1998)
  - 4-5% probability

Unknown Inclinations

- Probability of face-on orbit too low to fuss about
  - P(i): i<45° = 30% vs. 45°<i <90° = 70%
  - High inclination → planetary masses

...still...

- In a large enough sample, expect to find a few binary systems

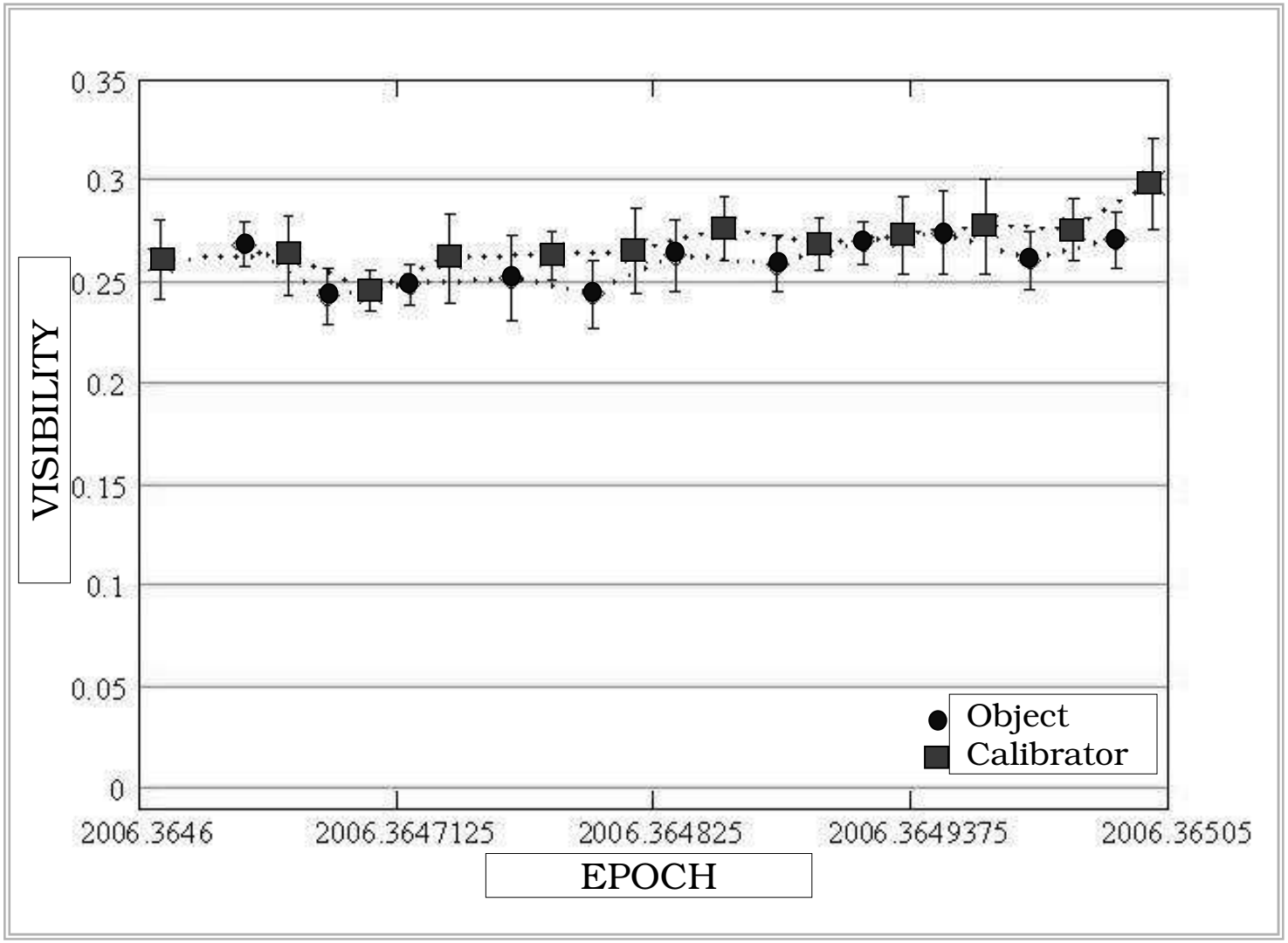
Methods

1. Compare visibility trends between target and calibrator

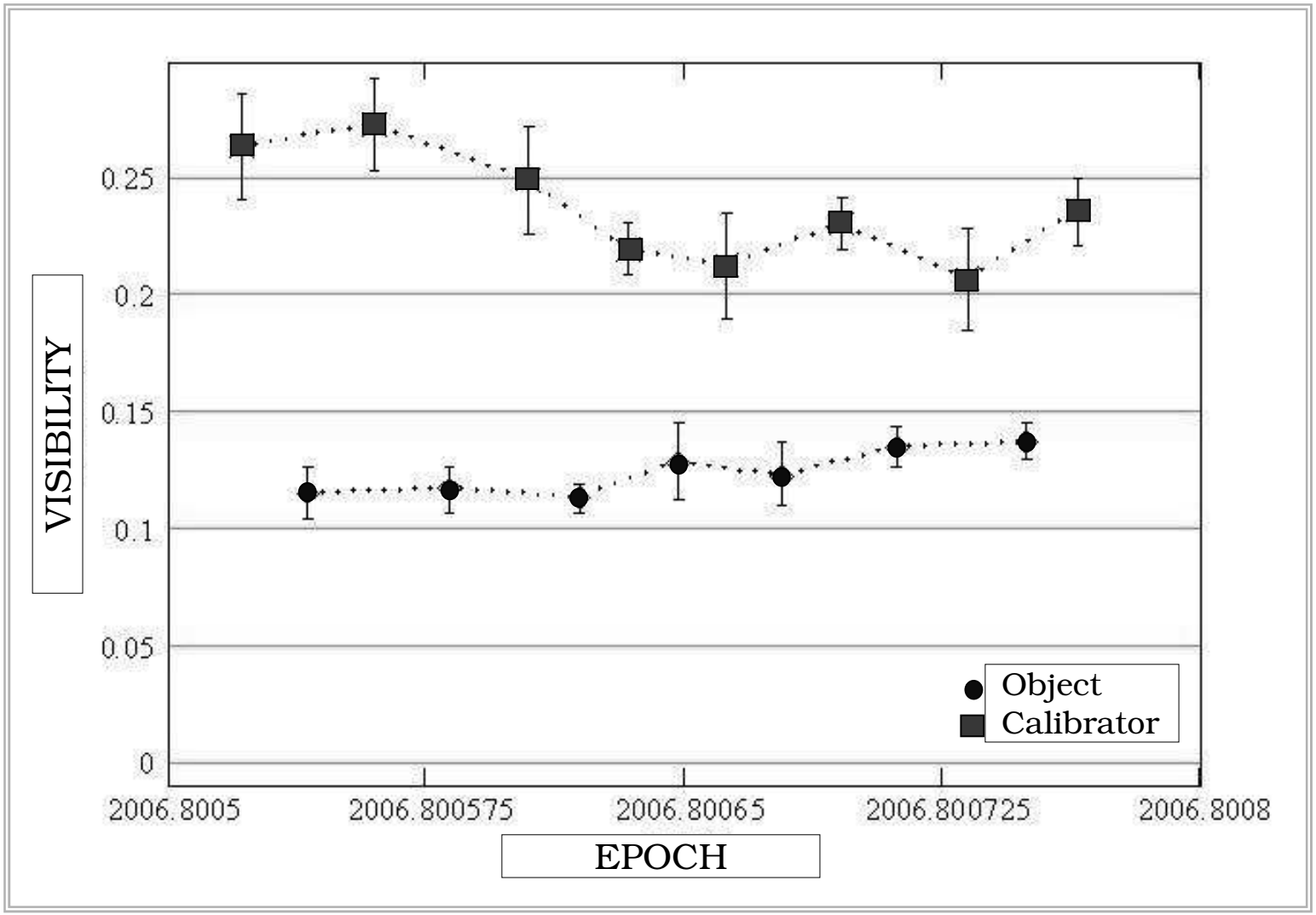
2. Inspect residuals to visibility curve fit

3. Look for separated fringe packets (SFPs)

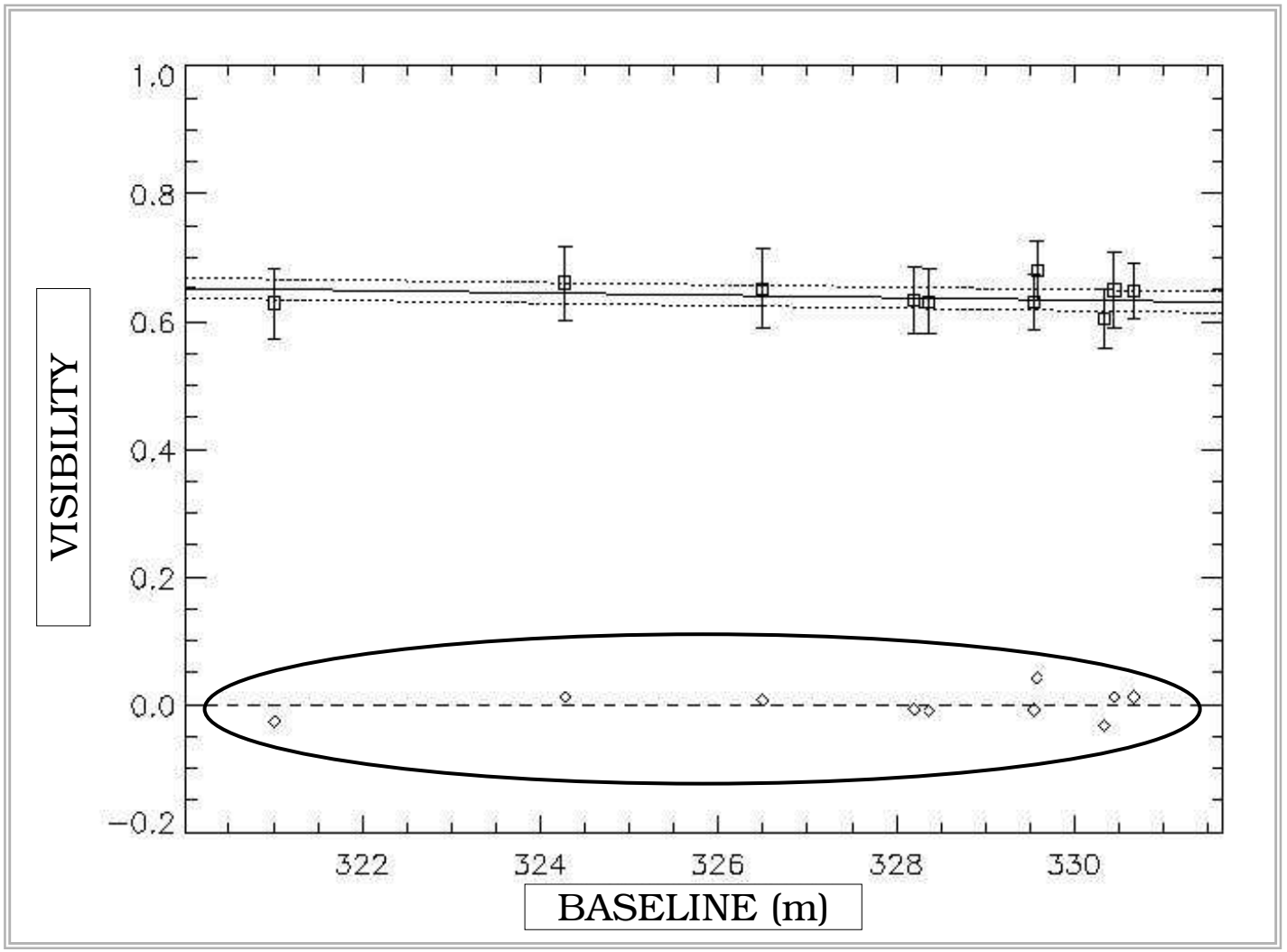
1. Normal Tracking



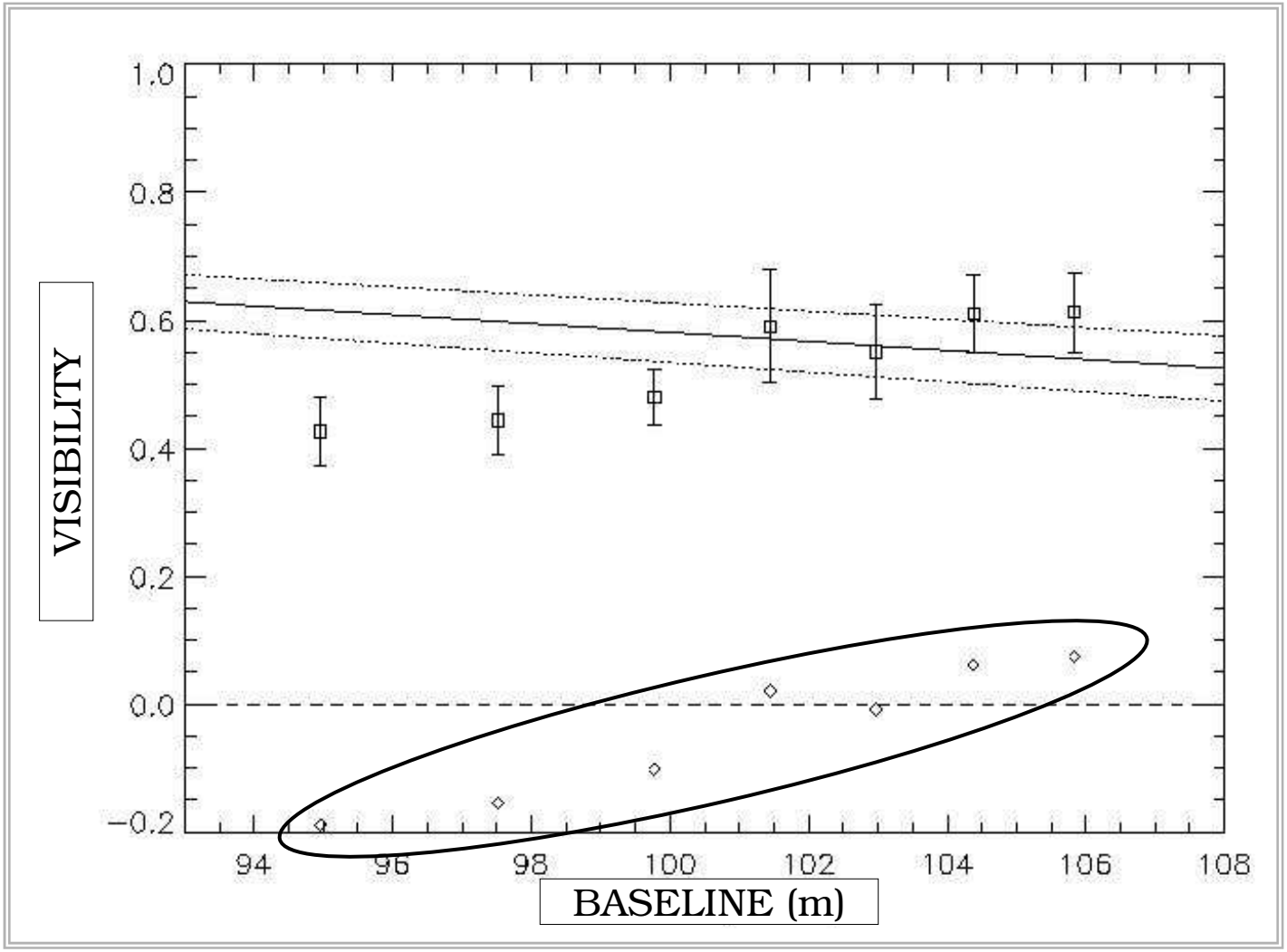
1. Unusual Tracking



2. Single Star Residuals

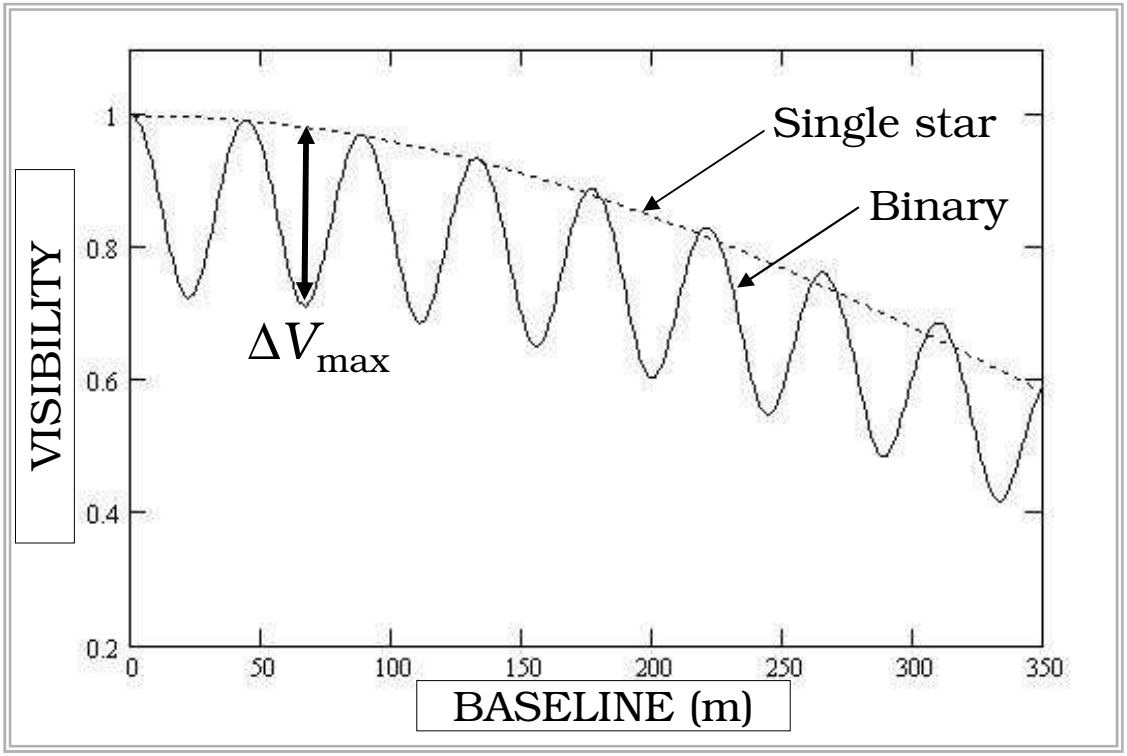


2. Unusual Residuals



2. Single vs. Binary

- Visibility curve for a binary with a given secondary type was created
  - G5 V
  - K0 V
  - K5 V
  - M0 V
  - M5 V



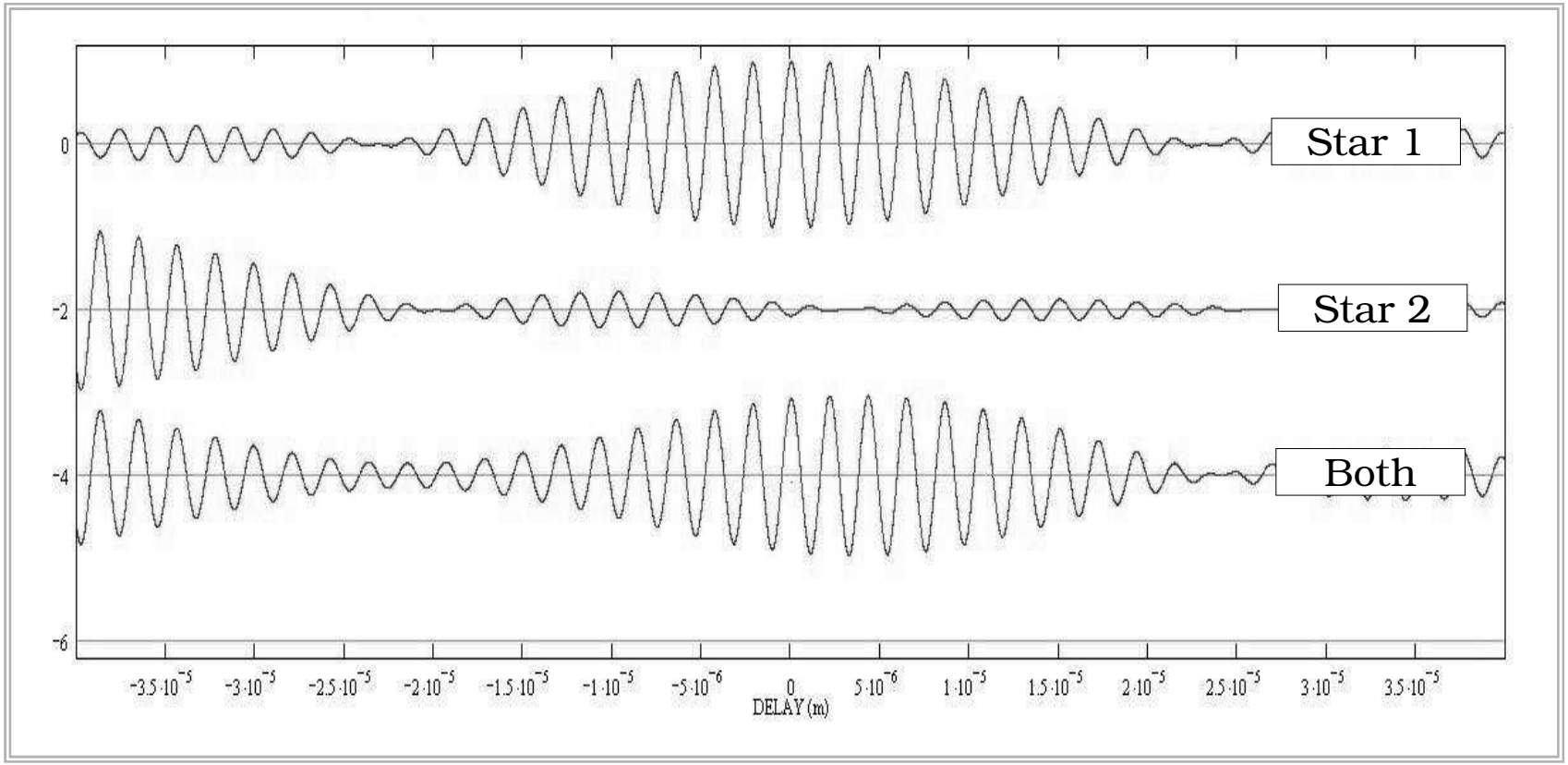
2. Example

σ_{resid}	ΔV_{max} G5 V	ΔV_{max} K0 V	ΔV_{max} K5 V	ΔV_{max} M0 V	ΔV_{max} M5 V
0.100	0.325	0.250	0.210	0.190	0.165
Observed	Theoretical				

- If $\Delta V_{max} \geq 2\sigma_{resid}$, that secondary spectral type could be ruled out

- G5, K0, K5 V ruled out; M0, M5 V still possibilities

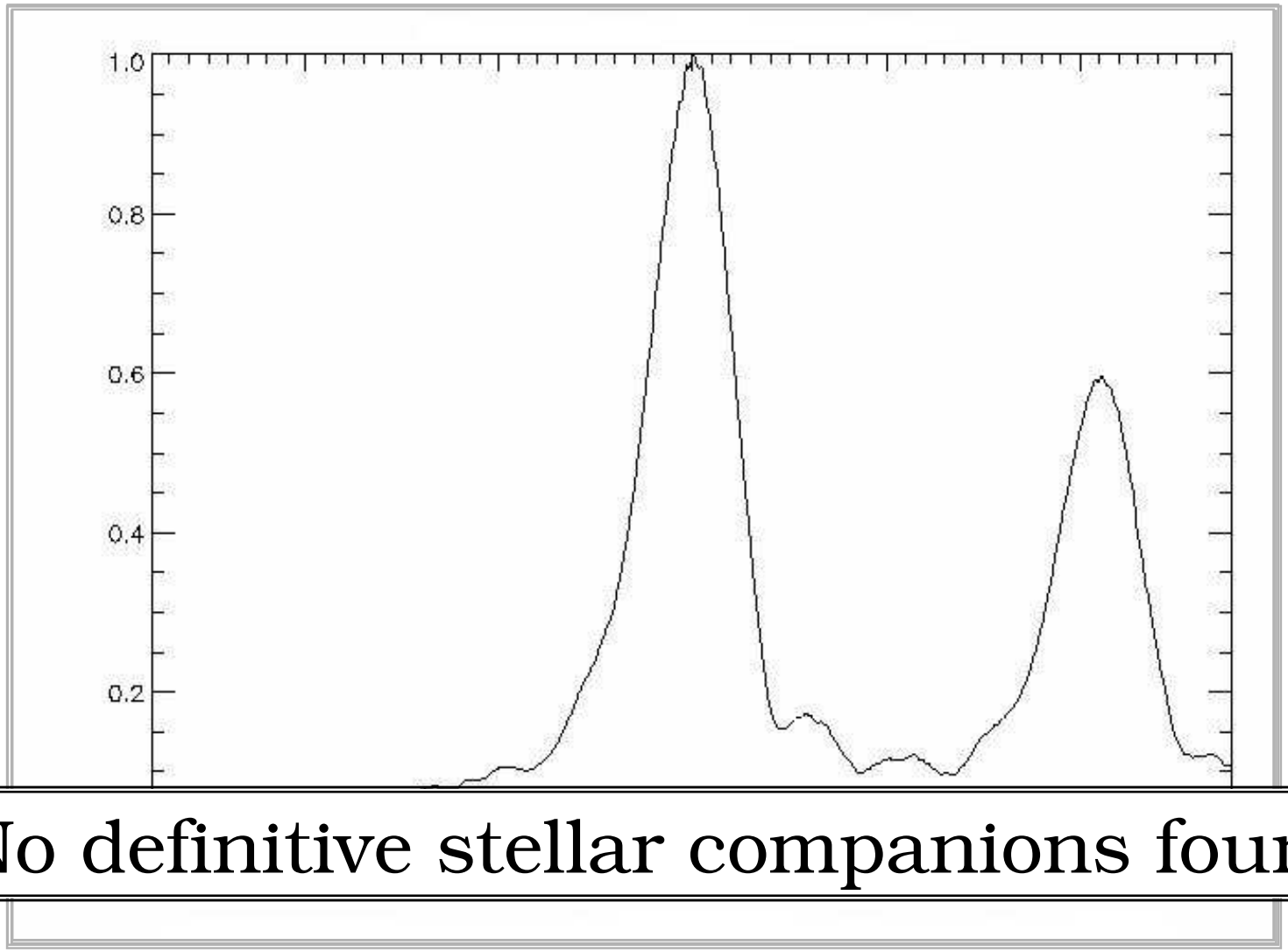
3. Separated Fringe Packets



3. Shift and Add Method

- Find each fringe packet in each of the ~200 scans
- Fit fringe envelope
- Shift each fringe so peak is in the center
- Add fringe amplitudes together
- Result: fringe envelope plot

3. Single vs. Double



No definitive stellar companions found

Recent Results: Measuring μ Cas A

Boyajian et al. 2008, ApJ, August 20

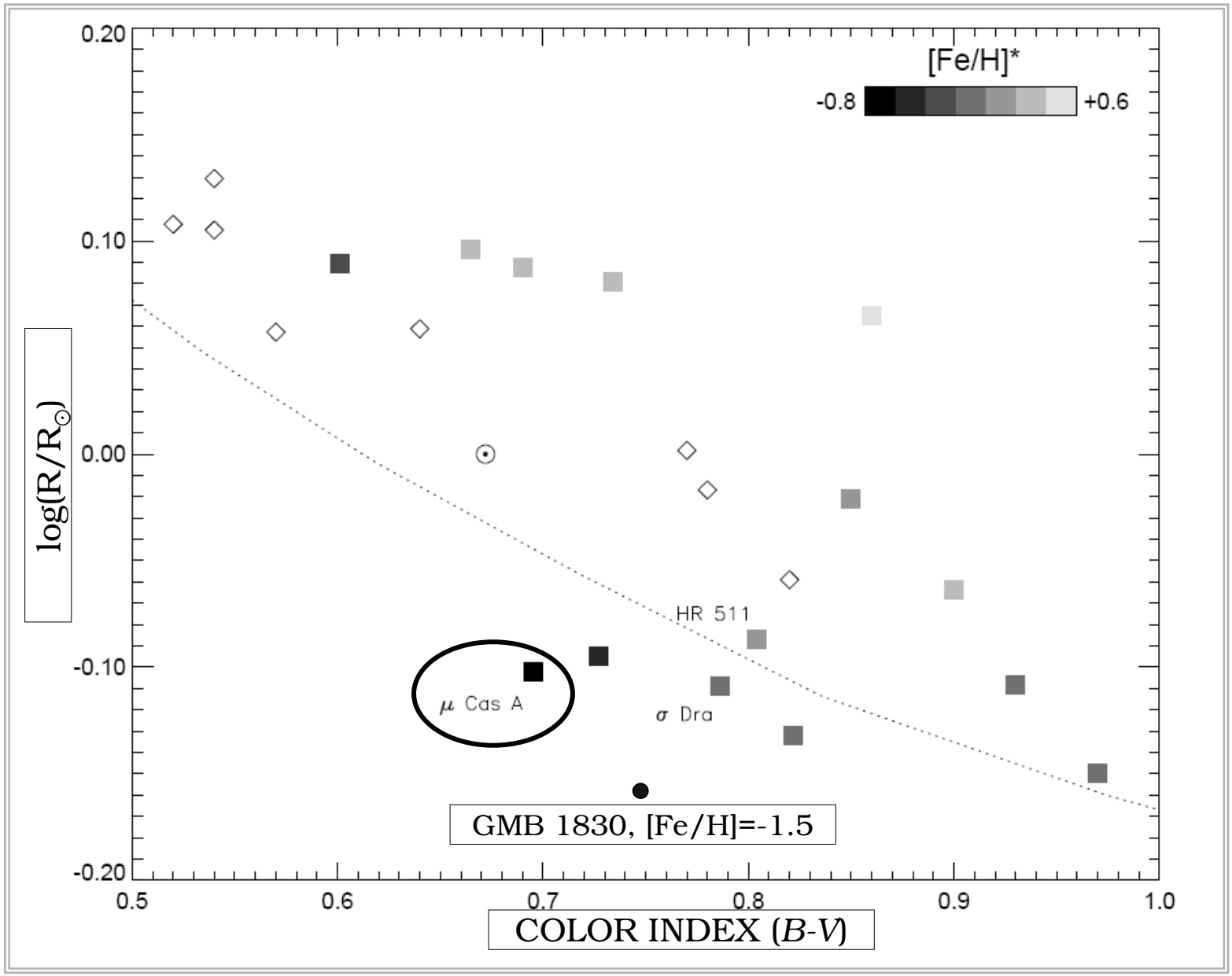
μ Cas A

- G5 subdwarf
- Halo population star
- Metal poor

- Higher-metallicity comparison stars:
  - σ Dra, K0 V
  - HR 511, K0 V

Results

- $\theta_{LD} = 0.973 \pm 0.009$ mas
- $R = 0.791 \pm 0.008\ R_{\odot}$
- θ_{LD}, $F_{BOL} \rightarrow T_{EFF} = 5297 \pm 32$ K
- $L = 0.442 \pm 0.04\ L_{\odot}$


[Fe/H]*
-0.8
+0.6
0.20
0.10
0.00
-0.10
-0.20
log(R/R⊙)
HR 511
μ Cas A
σ Dra
GMB 1830, [Fe/H]=-1.5
0.5
0.6
0.7
0.8
0.9
1.0
COLOR INDEX (B-V)

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www.chara.gsu.edu/CHARA

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